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ABSTRACT

Indicating that the rationale for teaching physics, to which curricula are ultimately directed, must focus on the needs of both future scientists and non-scientists alike, trends in physics curricula and instruction are viewed. Such changes are suggested to have taken place in response to growth in information, to changing perceptions of the nature of the physics discipline, and to a variety of other factors in the surrounding community and society. Following a review of physics enrollments and the state of physics in the late 1950's, science course improvement projects begun at this time are reviewed, including, for example, the Physical Science Study Committee Physics course, Nuffield Physics Project, Project Physics (formerly Harvard Project Physics), Berkeley Physics Course, Intermediate Science Curriculum Study, and Man Made World. Discussions of other trends in physics address student grouping and pacing, relevance through applied science and societal issues, role of the laboratory, use of resource materials and media, role of the teacher, and the role of research on learning and development in the curriculum development process. (DC)

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Technical Report #24

ISSUES IN PHYSICS EDUCATION

In Historical and Contemporary Perspective

by

Vincent N. Lunetta

ISSUES IN PHYSICS EDUCATION

In Historic and Contemporary Perspective

Vincent N. Lunetta
The University of Iowa

Science Education Technical Report # 24

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Robert E. Yager, Coordinator
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Over the past century and especially in recent decades there has been an unprecedented and exponential explosion of information and productivity in the world of physics and related sciences and technologies. Science and technology are now inextrictably woven within the fabric of the world's more developed societies. Teaching "the natural philosophy", not too long ago a peripheral part of academe, has become far more central and even "basic" in contemporary schooling. In this scientific age, physics no longer has to fight for academic respectability though it has not fared well in the competition for students, and the nature and orientation of the physics curriculum are still subject to some debate.

The rationale for teaching physics, to which curricula ultimately are directed, can be reduced to two global goals: (1) providing experiences that will enable some students to reach the frontiers of physics and the other natural sciences to make scientific and technological contributions in their own right, and (2) providing a foundation of general understanding for students who will not specialize in the sciences that will be sufficient for enlightened citizenship in a technological age. These two goals for physics education address both professional and broader cultural needs and are implicit assumptions underlying the development of physics curricula. Yet, curricula based upon these goals have taken a variety of forms.

Physics curricula over the years have evolved in response to growth in information, to changing perceptions of the nature of the physics discipline, and to a variety of other factors in the surrounding

community and society. These factors have included changing notions about how people learn, changing populations and realities in schools, and changing societal needs and values. What is thought to be relevant in an age of steam engines may become more trivial in an age of electronics; what is thought to be relevant in an early industrial society may become more trivial in a society concerned about environmental degradation or nuclear holocaust. These values have had indirect but powerful effects on science curricula generally and on physics curricula specifically.

An Historical Perspective. The exponental growth in information within physics over the past decades has been accompanied by growth in the numbers of students enrolled in physics courses. In the United States, for example, in 1930, approximately 100 Ph.D.'s degrees were awarded in physics. In that same year approximately 200 students received physics master's degrees and about 1,000 physics majors received bachelors' degrees. The figures were approximately 1500, 2500, and 6000 in 1970 falling to about 1000, 1500, and 4500 respectively in 1980. The numbers of non-majors enrolled in university level physics and physical science courses grew even more dramatically during that time, and the number of students studying physics in secondary schools rose at an even greater rate to about 600,000 per year in the United States reflecting the increasing proportion of the society enrolled in secondary education.

The basic topical organization of physics textbooks remained relatively unchanged from the mid-1800's through about 1960. During

that century emphasis upon the laboratory or didactic instruction, upon pure science or technology, upon facts or conceptual schemes ebbed and flowed, but by the late 1950's the stage was set for dramatic change in physics curricula especially at the secondary school level. Studies of curricula at that time indicated that textbooks "no longer reflected the views of the scientific community, ... attempts to add new material had resulted in a patchwork quality in which the unity of physics had disappeared, ...new material reflected the increasing importance of technology...but resulted in...further minimizing of the concepts of the science itself." (Little, 1959).

Curriculum Overview. The most visible revolution in physics curricula began in the late 1950's at the secondary school level with corollary waves of change at primary and tertiary levels as well. These changes received extensive financial support from government and private sources in both Great Britain and the United States, stimulating similar curriculum revision and development in many countries throughout the world. The first of the major curriculum projects of this period and the one having the most profound influence on other projects was prepared by the Physical Science Study Committee (PSSC). The PSSC curriculum development efforts brought together several hundred high school and college teachers with millions of dollars of support to develop the PSSC Physics (1976) course designed to:

(A) present physics as a unifed yet living and ever-changing subject
(B) demonstrate the interplay between experiment and theory in the development of physics

(C) have the students learn the basic principles and laws of physics by interrogating nature itself...
(D) extend the student's ability to read critically, to reason and to distinguish between the essential and the peripheral,...
(E) provide a sound foundation for those students who plan to study science or engineering at the college level.

The Physical Science Study Committee designed an intensive course around a few fundamental areas of physics. To accomplish this objective a number of topics normally treated in more traditional courses were eliminated from the course outline. Thus, for example, there was no section of the course devoted to a study of sound. On the other hand, light and wave motions were treated in great detail with a laboratory-centered orientation in which models of light were developed very carefully. Applications of physics were eliminated almost entirely from the PSSC curriculum which included a text, laboratory guide, simple but profound laboratory apparatus, films, and a series of supplemental monographs. The Physical Science Study Committee also developed a variety of other curriculum materials including an advanced topics course, two physical science courses for junior high school students, and a collegiate edition of the physics text.

In Britain, the Nuffield Foundation initiated a number of science curriculum development projects to renew science teaching in British grammar schools. In 1962 Nuffield (1967) initiated a curriculum

leading to the "O-Level" examination for 16 or 17 year old students. (Secondary school physics experiences in Great Britain are spread throughout five years, and students take different science subjects concurrently in each of those five years, in contrast with separate

one year courses common in the United States.) The Nuffield Physics Project was intended for the upper twenty-five percent of students based on academic ability, "and the program was to make science intellectually exciting for [students], and to bring them through their own investigations and arguments, to an understanding of what science is, and as far as possible, of what it is like to be a practicing scientist." Thus, the emphasis, as in the PSSC course, was on pure science, not on applications of science, and on important scientific processes and conceptual schemes. Interwoven conceptual schemes built up knowledge of materials, waves, energy, and atoms, and the project resulted in the production of Teachers' Guides, Guides to Experiments, Question Books, A Guide to Apparatus, and Tests and Examinations. One of several related efforts was the Nuffield Advanced Physics Project (1972),
a two year course for students in the sixth form (ages 16-18). The advanced course emphasized use of numerical methods and selective development of mathematical skills. While flexible use of the ten units and materials was encouraged, the course was to culminate in a study of the particle-wave nature of electons and photons and the nature of simple atoms.

A third secondary level physics project having substantial international impact was Project Physics,(1981)formerly Harvard Project Physics, initiated in the United States in 1964. Project Physics was intended to increase the appeal of physics to a broader range of high school students by emphasizing the humanistic roots and consequences

of physics. The project hoped for an integration of history, culture, technology, and people in the development of physical ideas. It hoped to present physics as an intellectual pursuit rather than as applied technology, to reduce dependence on complex mathematical skills, and to reduce perceptions of difficulty commonly associated with the study of physics. In addition to the text, course materials included film loops and film strips, films, overhead transparencies, programmed instruction booklets, teachers guides, a student handbook, and readers. The readers represented an especially unique innovation for they were anthologies intended to encourage supplemental readings taking students out beyond the normal confines of a physics course and enabling them to pursue special personalized interests. Project Physics also advocated some relatively innovative systems for personalizing instruction, managing the classroom, and evaluating students' progress.

At the tertiary level, physics curriculum development during and after the 1960's was less systematic than at the secondary level with textbooks for physics concentrators becoming generally more massive, mathematical, analytical, and abstract. Though they began to include more "modern" physics, they tended to provide little contact with philosophical inquiry and with more descriptive, phenomenological study. International attention was garnered, however, by a few creative individual authors, like Eric M. Rogers and Richard P. Feynman, and projects, The Berkeley Physics Course (1973) being one of the most noteworthy. (The Berkeley project included the production of a series of electronic analogue laboratory activities that were widely discussed in the 1960's and early 1970's).

Many other courses having physics connections were initiated during the science curriculum development wave of the 1960's. These included well-known primary, secondary and tertiary level physical science and unified science courses such as: Intermediate Science Curriculum Study, ISCS, (Burkman, et. al., 1975) a junior high school program, Physical Science for the Non-Science Student (PSNS, 1969) a tertiary program, and Man Made World (Engineering Concepts Curriculum Project, 1971) to name just three. The ISCS program was written as a "self-paced" series of activities involving "core" activities for all students with optional remedial and enrichment excursions. Man Made World, on the other hand, was designed with an applied physics orientation intended to contribute to the technological literacy of high school students of average to above average ability. The course presented some of the ideas covered in conventional physics courses but went beyond them to examine systems and to present concepts and processes such as stability, change, feedback, optimization, simulation, modeling, and programming. The search for alternative solutions for complex societal and environmental problems was a major theme. The course was intended to inject a greater number of alternatives into the secondary science curriculum but its creative pluralism also proved to be a liability since few secondary schools were ultimately able to find a place for it as a part of their curriculum and budget. Its attention to societal relevance, however, was a precursor to a major movement in that direction among many introductory physics courses especially those for tertiary level non-majors that flourished a decade or more later. At the primary school level,

some excellent activity-centered science programs were developed that included the exploration of many physical phenomena. These materials including the Elementary Science Study in the United States and Science 5-13 in Great Britain, to cite only two examples, incorporated some of what is known about human learning and development and provided outstanding source materials for physics curricula at all levels.

Due to changing societal priorities and to increased competition for limited funds, science curriculum development efforts declined sharply in the 1970's and a number of the projects spawned in the 1960's died an early death. The projects sampled in this review, however, have generally been revised and have had world-wide impact with translations in many languages. Though use of the actual project materials in the country of origin has generally declined, commericially prepared textbooks and laboratory handbooks in use two decades later provide evidence of the strong impact of these curriculum projects. Nevertheless, declining enrollments in physics and physical science courses and reduced public support for science education in the United States and many places in the British Commonwealth in the 1970's and the early 1980's provide reason to wonder about the ability of those societies to cope with the multitude of complex problems at the interface of science and society that lie ahead.

Student Grouping/Pacing. The most common pattern of grouping students in physics classes has been by ability and career orientation. The Commission on College Physics in the United States in 1960 recommended two different curricula at the collegiate level, one for

students planning graduate study in physics and another for students who were specializing in other fields or planning to teach physics at the secondary level. This pattern enabled physics-oriented students to use calculus early in the study of basic physics while others could be involved in physics with less developed mathematical skills thus meeting the needs of an increasingly diverse student population. Especially in secondary schools in the U.S.A., however, this homogeneous grouping pattern came under strong attack in the mid-1960's as an elitist and undemocratic system that discriminated against students with less academic educational and cultural backgrounds. As a result there was movement toward more heterogeneous groupings of secondary school students, and new systems of management were developed to respond to the increased diversity of students within the same class. In that period many teachers explored "Keller plan", "Individualized", "Self-paced", or "Personalized" forms of physics instruction. In such courses, students move individually or in small groups through core and optional modules at different speeds presumably compatible with their own needs and interests. Special curriculum materials were prepared to support such personalized courses; the ISCS and the Project Physics materials mentioned earlier in this review are two of several different models. While some but not all students and teachers clearly preferred such approaches and while learning has not been inhibited for many students in these courses, they provided no panacea. Teachers in "mainstreamed" physics classrooms, often without adequate resources, support, and skills have been confronted by the great

difficulty of reaching the noble goals of schooling with a very diverse classroom population.

Applied Science/Relevance. The visibility of applications in physics curricula has waxed and waned over the years partially in response to societal values. In the preface to the 1929 edition of New Practical Physics, Black and Davis wrote: "...the study of elementary physics should begin with...the fundamental principles that underlie the construction and operation of many familiar machines and devices that surround us..." In the mid-1950's, however, physics courses were criticized for including a proliferation of technology, and the early waves of new curricula in the 1960's eliminated applications of physics almost entirely. Subsequently, the lack of relevant applications has been cited as one of the causes of the decline in student interest and enrollment. Work with the applications of science apparently makes the study of physics more relevant and appealing to large numbers of students. Thus, in the development of introductory physics curricula, it is important to search for an optimal balance between pure science and the applications of science. Surely, it is important that students be able to discriminate between science and technology and to have an understanding of their interrelationships. The probability of such understanding is increased when it is addressed within a physics course.

During the 1970's a number of groups began to advocate emphasis upon career awareness in introductory science curricula. Concurrently environmental problems at the interface of science and society were

becoming more visible, causing further demands for relevance in science teaching from groups both within and without the physics teaching profession. Subsequently, groups all over the world have advocated the use of societal problems as foci for study in science. Many of the papers in the GIREP Conference of 1979 document this concern (Ganiel, 1980), and a number of texts and supplemental materials emphasizing the societal context (e.g., Lewis, 1981) have been prepared. At the collegiate level during the 1970's there were a proliferation of physics offerings for non-majors with titles like: The Physics of Sound and Music, Environmental Physics, and Physics for Artists, due in part to a growing perception of the need to communicate with the non-scientific community and in part to declining enrollments in physics. It is important to note that there are some large differences between skills and understandings in elementary physics and the skills involved in decision making on complex societal issues having large social, economic, and values laden components as well as engineering and science dimensions.

The Nature of Science and the Laboratory. There is evidence that students often acquire a simplistic view of science through school science curricula, a view that is isolated from their reality and from the reality of scientific process. Yet, over the years many have written that the physics curriculum should reflect the nature of physics, and developing an understanding of the nature and process of science has been among the more important goals of physics teaching. A primary concern of the major physics curriculum projects was to

communicate that physics is more than a collection of facts and static concepts and laws; it is a way of learning about the physical world; it is a growing, dynamic network of evolving models and conceptual schemes. In an attempt to communicate this view, the major secondary level projects of the 1960's planned to highlight some of the history of science and to emphasize the central role of the laboratory. Students were to explore phenomena in the laboratory and to make generalizations about relationships; they were then to further develop these generalizations and models and test them in the laboratory. Based upon the new data, the model would be refined further or discarded. The process included a mix of both inductive and deductive thinking with much more emphasis on inductive thinking than had been present in the earlier physics courses that preceded them. It was intended that students would not only learn scientific concepts but also learn about "the way of the scientist".

Through open inquiry, it was anticipated that students would develop a variety of scientific skills in planning and designing, in observing and interpreting data, and in explaining relationships and developing models. The task of helping students reach the dual objectives of conceptual and methodological understanding is not a simple one, and there are many complex variables yet to be addressed by researchers and curriculum developers. There are, for example, discrepancies between goals stated for physics curricula and the activities actually found in the published materials. Among other things, it has been difficult for publishers to package and for teachers to manage activities

that include open inquiry. Emphasis on the role of the laboratory has also oscillated over the past decade, but relatively few physics educators question the importance of laboratory activities. The questions that do arise relate to the optimal quantity and the design of appropriate laboratory activities (Lewis, 1980). There is some evidence suggesting that such activities can motivate students while assisting in the development of problem solving and reasoning skills.

Materials /Media. Over the past 100 years there has been exponential growth in knowledge about the physical world. Concurrently, there has been great growth in the apparatus, material resources, and media available for physics teaching as well. With relatively simple though not necessarily inexpensive apparatus, students today can easily observe some of the fundamental phenomena of physics such as motion in almost frictionless conditions and interference effects in light. They can experimentally determine not only the wave length but also the velocity of light, and they can observe the diffraction of electrons. The availability of high quality films showing physical phenomena has grown exponentially, though use of such films in secondary education has been limited due to high costs. On the other hand, many introductory physics classrooms make regular use of shorter "single concept" film loops which are less expensive and which provide more flexibility for teachers. These films are sometimes prepared to be used as secondary data sources in which phenomena that are too dangerous or costly or massive are filmed and students make experimental measurement directly from the projected image.

One of the realities of education, especially in secondary schools, is the small amount of money available per student to support the purchase of media and laboratory equipment. Thus, many schools are not well stocked with equipment to support student activity, though many do have a moderate collection of equipment for class demonstration. Thus, there has been a call for using simpler apparatus and for studying the physics of everyday phenomena in the environment. Several groups like the PSSC and UNESCO (Inexpensive Science Teaching Equipment Project, 1972) have designed appropriate apparatus for student activity at low cost, but for a variety of complex reasons, teachers have not rushed to construct, use, and maintain such equipment over an extended period.

In the 1970's the advent of inexpensive electronic calculators revolutionized methods of computing for physics students. The arrival of this new technology provided an array of new possibilities for strategies of physics teaching, but for the most part, the calculator is being used in relatively conventional ways to determine discrete solutions to problems that are often one-dimensional. Calculators have the potential, however, to help students develop higher levels of skill and conceptual understanding through the use of new strategies of teaching and learning. The insensitive use of calculators may also be one of the factors contributing to the declining ability to estimate and to understand fractional relationships, for example, that are visible in contemporary assessment data. Also, the fact that enrollments and interest do not appear to have been enchanced with the advent of easily accessible help in computation suggests that those problems may have

deeper roots than simply "the tediousness of computation."

The revolution caused in the 1970's by the advent of inexpensive hand calculators pales into insignificance when contrasted with the potential impact of the micro-computer on physics education. Digital and analog computers have become major research tools in physics and in the other sciences since the 1950's, but by the 1980's, as this review is written, their power in instruction has not yet begun to be felt. As a matter of fact, advocates of computer based education have discovered greater difficulties than they had anticipated in introducing the computer as an appropriate medium of instruction. Yet, there are many signs that interactive computing will become a major way of learning aspects of physics in the next two decades. Though activities in the laboratory will continue to have a major role in the development of certain skills, the probability is high that appropriate computer based simulations of phenomena will grow in importance as a medium of instruction.

The Teacher. From time to time, in response to great variations in the quality of teaching and of teacher preparation, physics curriculum writers have set about the task of creating "teacher-proof" curricula that would be so complete and effective that even the poorest teachers could do little harm. That, however, has proven to be a most elusive goal. There is much evidence that good experiences, especially at the introductory level, do not demand a high investment in materials but do require an effective teacher. Experiences with a good teacher are enhanced when he or she has access to good material resources,

but good materials alone are insufficient. Today's teachers generally have access to an array of curriculum resources, but the teacher remains a critical ingredient in the quality of the educational experience for the majority of students.

While there is much we must yet come to understand about how students best learn physics, some large discrepancies are visible between commonly stated goals for physics teaching and what students do in classrooms. These discrepancies may well be among the factors contributing to the disenchantment with science generally and with physics in particular and to the relatively low levels of physical understanding revealed in large data samples gathered by groups like the National Assessment of Educational Progress in the United States. To cite only one example of this kind of inconsistency, testing and evaluation in the classroom often assess only a narrow subset of skills that physics teachers hope to help students develop. Reviews of tests and evaluation systems in introductory courses indicate that they often emphasize replication and naming of relationships, rote cranking of numbers through inadequately understood algorithms, and other relatively low level cognitive activities. In fact, effective evaluation should assess development of practical and problem solving skills as well as the development of conceptual understanding. Similar comments can be made about other dimensions of physics teaching.

There is reason for concern about the quality of preparation of physics teachers, especially at the secondary levels, for many persons who are well qualified to teach in the physical sciences are drawn off

to more financially lucrative occupations, and their places are filled by less qualified teachers. In many western countries, concern for this problem is not perceived as a high priority by governments at this time. On the other hand, national and international professional associations, publications, and communications networks exist today enabling mutual interaction and growth for the community of physics teachers that provide alternative avenues for growth and development.

Research on Learning and Development. In developing curricula, physicists and science educators should have high standards for research and development in instruction similar to their standards for research and development in physics itself. Curriculum development projects have seldom incorporated thorough research programs, though Project Physics did incorporate a careful and extensive program of research and evaluation summarized in Welch (1973).

Optimally, physics curricula and teaching are firmly rooted in learning theory as well as in the science of physics. While there is much we yet need to know about how people learn, some generalizations can be made that are based upon the research literature. Gagne, Bruner, Ausubel, and Schwab have examined the effects of various aspects of the structure of disciplines on learning. Others, for example, Osborne (1980), have examined the development of scientific concepts from a more student centered point of view using carefully developed interview protocols. These studies reveal some very common patterns of thinking that are frequently inconsistent with views of organized science and indicate the great importance of understanding and

responding to the student's prior knowledge and conceptual schemes in teaching new concepts.

In addition, other researchers have examined the development of reasoning (Karplus, 19 78). Researchers examining models organized by Jean Piaget have studied patterns of logical and spatial thinking that are highly relevant to the teaching of physics, and the existence of defined hierarchies of thinking has now been well validated. In some cultures people tend to be at different levels of logical development than in other cultures, and within a culture, there will be great variation across individuals in their own development. While the current level of knowledge of developmental thinking does not enable curriculum writers to be highly prescriptive, it is a dimension of great consequence to which both authors and teachers ought to be sensitive. There is evidence that in the presentation of certain topics, some introductory texts assume logical skills that have not been developed by large portions of the student population for whom they are intended. Piagetian research is often cited as evidence that students should manipulate real materials as an important part of the development of thinking skills. Related studies of the development of "problem solving" skills are currently an area of considerable research potential.

When one reviews the data on people's scientific understanding and on enrollments in school science, there is ready evidence of some serious problems. Yet the situation is a complex one as are most of the problems at the interface of science and society, and it is naive

to assume that the answers to these problems should have been simple or immediately obvious. While education in physics has not been responsive to all the dimensions affecting the quality of teaching and learning in physics, some excellent curriculum resources now exist as a result of the era of massive curriculum development that began in the late 1950's. In addition, there is new information and data as a result of that experience that can provide a basis for new steps in curriculum development in the future. The search for an optimal curriculum will be a continuing one, for that curriculum will be responsive to changes in the needs of students and society as well as to changes in understanding of physics, learning, schools, teachers, and the evolving cultural context.

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